# Evaluating Short Openings as a Management Tool to Maximize Catch Rates in Catch and Release Fisheries

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## Abstract

## Introduction

Catch rates are often cited as the primary determinant of satisfaction drawing anglers to fishing (Arlinghaus 2006). Consequently, catch rates are also a key rate that managers attempt to maximize. The actual rates in which fish are caught are dependent on a number of factors, including fish behavior, angler behavior, angler skill and abiotic factors such as weather and temperature. Obviously, only some of these factors can be indirectly controlled of managers.

Managers may try to manipulate aggregate catch and catch rates through a combination of fishing regulations aimed at altering angler behavior, effectiveness or likelihood of harvesting captured fish. Regulations are typically classed as either input controls, which limit where, when, and how many anglers are permitted to fish (e.g. time, area closures and limited entry harvest, respectively), or output controls, which limit the number and types of that can be harvested and the effectiveness in which they can be captured (e.g. bag limits, size limits and gear restrictions, respectively). Each of these regulation types has a set of specific uses for both achieving particular fishery objectives and for conservation.

Catch and release regulations are often used as a way of maintaining fishing opportunities in situations where harvest might lead to collapse or other conservation concern. Catch and release has gained prominence as a management tactic, with many anglers voluntarily releasing their catch. While releasing all captured fish helps reduce mortality and ensuring plenty of fish remaining to be captured repeatedly, there may be unintended consequences to catch and release. One such consequence is the frequent refrain that catch rates are lower later in the season. While this may be due to behavioural changes in fish as water temperature warms, this may also be due to fish being temporarily unreactive to fishing gear. This may be due to fish learning to avoid fishing gear or fish temporarily changing behavior as they recover from the experience or both. Catch and release regulations are typically only used in conjunction with temporary closures that protect particularly vulnerable times in the species life cycle, such as staging, spawning or nest guarding.

Fishing effort is often highest immediately after opening a fishery. This reflects a utility for above average catch rates.

If fishing utility is highest immediately following the opening of a fishery, and there is an exchange between vulnerability states, it may be beneficial to implement catch and release regulations with infrequent fishery openings across a landscape of discrete (small lake) fisheries. Doing so would theoretically attract fishing effort and maintain high catch rates on opening days while still provide sustainable fishing due to the lack of harvest. When implementing this strategy across multiple lakes, it may attract more effort than if all lakes were constantly open, while maintaining a higher mean catch rate across the season.

We propose using a series of rotating closures across a landscape of similar lakes managed as catch and release as a means of improving aggregate catch rates and total fishery value while not limiting access to fishing opportunities. Effectiveness of this management tactic will be evaluated through simulation. Finally, we will discuss how to experimentally measure exchange rates and how to set up the spatial opening tactic on a landscape fishery.

## Methods

### Model development

The model assumes there are three primary states with respect to vulnerability to being captured: vulnerable, invulnerable and refractory (Figure 1). Vulnerable fish are in areas of the system where they are available to anglers and in a behavioural state where they will react to fishing gear. Invulnerable fish are not available to anglers because they are in an area of the system or a behavioural state where they will not be captured by anglers. Vulnerable fish that have been captured and released are in the refractory state, where they are unwilling to react to fishing gear even if they are otherwise available to be captured. These fish will eventually move into one of the other states.

The single lake model is described in Table 1; parameters and variables are given in T1.1 and described in Table 2. At the start of the year, the population is assumed to be in equilibrium, with no fish in the refractory state and fish in the vulnerable and invulnerable states dictated by the vulnerability exchange rates (Eq. T1.2-T1.4). Effort on any day is a logistic function dependent on expected catch per unit effort and scaled to the maximum effort. Realized effort will be the zero if the lake is closed to fishing on a particular day (*Ot*=0; T1.5). Abundance in each vulnerability state is updated daily by accounting for catches (T1.6), discard and natural mortality, exchange rates between states and appropriate allocation of recovered to vulnerable and invulnerable states (T1.7-T1.9).

The landscape model takes the model described above and accounts for multiple lakes at different distances to a single angler population center (sensu Cox et al. 2003, Parkinson et al. 2004). Effort to each lake is defined as a two-stage process. Total effort on a particular day depends on the total number of vulnerable fish across all lakes weighted by the distance those lakes are from the population center. **Expand…**

**Discuss distribution of openings across landscape (mention staircase design)**(Walters et al. 1988)

### Value metrics

The value of recreational fisheries is often perceived differently from commercial fisheries. While catch is an important attribute, there are many other factors to consider, particularly in a catch-and-release fishery, as is being represented here. Fisheries managers often view catch-per-unit effort as a key metric for tracking the success of their management actions, as it is one of the few outputs for which they have some level of control. Likewise, fishing effort is often viewed as an important measure of management success, presuming that more fishing trips implies more satisfaction.

Satisfaction, which is the difference between expected and realized outcomes (Arlinghaus 2006). Recreational fishing outcomes are a complex suite of social and economic factors and determining satisfaction based on these outcomes is difficult to quantify. We propose an adaptation of the Cox et al. (2003) assumption that total economic and social va ues combine to provide a linear value function. Our value function again assumes that there is a minimum CPUE at which satisfaction becomes zero, but relaxes the assumption that it increases linearly:

*S* in equation 1 is the average value or satisfaction per angler-day (AD) associated with the “potential” catch rate (CPUE; fish/AD; Cox et al. 2003), *C*0 is the CPUE at which S=0 and  describes whether satisfaction increases exponentially (>1), remains linear (=1) or saturates with CPUE (<1; Figure 2). Using equation 1, the total value of the fishery is the product of daily satisfaction (value per angler day) multiplied by effort on days when the fishery is open

1. .

### Model evaluation

The system was evaluated over a full year (T=360 days) with no seasonality in fish behavior or fishing effort. Using this model, six candidate opening schedules were evaluated to see how they compared with respect to total annual catch, effort, average CPUE and satisfaction. These candidate schedules included opening the fishery once or twice a week, once or twice every two weeks, once a month or always open. Once the schedule with the highest total value was found, this schedule was used in all later evaluations.

Model behavior was evaluated using two methods. First, the elasticity of total value for a single lake was evaluated against small changes in each of the parameters. Elasticity measures the proportional response of a function to a proportional change in parameter values (Allen et al. 2009). Elasticity was calculated as the proportional change in the total fishery value to an increase or decrease of each parameter by 10%. Both positive and negative changes were necessary because the influence of a parameter on a function may be asymptotic (van Poorten et al. 2011). The second evaluation of model behavior was to see how value varied as maximum effort varied up to 100 anglers per hectare per day.

The performance of the rotating closure management tactic has so far been predicated on targeted fish exchanging between vulnerable and invulnerable states. Although there are multiple suggestions that such a dynamic system is common in many fisheries, the prevalence of such a system is largely unknown. We evaluated the rotating closure tactic by comparing performance across systems with and without a vulnerable exchange dynamic in the fishery system. This was accomplished by setting *v*1=1 and *v*2=0. We still assumed that there was a refractory period in which fish are unavailable to anglers, although they all returned to the vulnerable state upon recovery (*pv*=1).

-seasonal/weather effects (multiple lakes)

## Results

Total catch of fish and fishing effort across the fishing season declines as the total number of days the fishery was closed per month increased (Figure 3). Effort declined faster across rotating closure scenarios than did catch. Consequently, catch per unit effort on days when the fishery was opened increased as the fishery is open less frequently. Total value of the fishery is evaluated as a function of catch-per-unit effort per angler day summed across fishing effort. When evaluating fishing value across rotating closure scenarios, value is maximized when the fishery is open one day per week (Figure 3).

In typical catch-and-release fisheries, a sizable proportion of all targeted fish are invulnerable to fishing at the start of the year (Figure 4, left panels). When fishing commences, fish are caught and released into the refractory state, which eventually recover into the vulnerable or invulnerable pool. The vulnerable pool rapidly depletes once fishing begins. Catch-per-unit effort immediately declines as a result of the reduction in vulnerable fish, and effort quickly drops off in response. Satisfaction immediately declines as catch rates and effort both quickly decline. In the hypothetical fishery demonstrated here, most satisfaction was realized in the first week.

Implementing a rotating closure where the fishery is open once per week alleviated many of the typical fisheries and management issues demonstrated in the typical catch and release fishery (Figure 4, right panels). The density of vulnerable fish declines much more slowly and stabilizes at a higher mean density because fewer fish are being caught and released. Effort per day remains near the maximum on days the fishery is open because CPUE stays above *C*50, the CPUE at which effort drops to 50% of maximum. Satisfaction does not approach the minimum for nearly 2 months and stays higher than the all-open fishery on days the fishery is open.

Total annual fishery value calculated by the model was most sensitive to initial fish abundance, survival rate of released fish and parameters used in the fishery satisfaction function (Figure 5). Elasticity was determined as the proportional change in fishery value following a +/- 10% change in the base model value (Table 2). Note that the base value of ** in the elasticity calculation was evaluated at 1.0 rather than 1.5 to demonstrate how the model responds to an exponential or saturating satisfaction function.

The rotating closures strategy contributes to a greater total fishery value than the all-open strategy across a wide range of maximum daily fishing effort (Figure 6). At extremely low effort there is little value in implementing the 1-day per week openings, but value quickly increases and reaches a maximum at moderate maximum effort. The value for an all open catch-and-release fishery declines almost linearly as maximum effort increases due to a decline in both daily CPUE and effort.

-spatial spread of effort with and without closing (landscape)

-compare alternate power parameters in the valuation of different scenarios (landscape)

-seasonal effects

## Discussion

Combining input and output controls

This scheme only works with catch and release fisheries

True value of this scheme depends on the shape of the value curve. More detailed

Experimental setup

## Acknowledgements

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Table 1: Recreational fishery simulation model for a single lake.

|  |  |  |
| --- | --- | --- |
| Parameters | |  |
|  | T1.1 |  |
| Initial population | |  |
|  | T1.2 |  |
|  | T1.3 |  |
|  | T1.4 |  |
| State dynamics | |  |
|  | T1.5 |  |
|  | T1.6 |  |
|  | T1.7 |  |
|  | T1.8 |  |
|  | T1.9 |  |

Table 2: Notation for the recreational fishing model.

|  |  |  |
| --- | --- | --- |
| Symbol | Value | Description |
| Indices | |  |
| *t* | {1,2,…*T*} | Daily time step (T=36) |
| *l* | {1,2,…*L*} | Lakes (L=12) |
|  | |  |
| Model parameters | |  |
| *N*0 | 1000 | Initial density of catchable fish |
| *q* | 0.05 | Catchability coefficient for recreational fishing gear |
| *v*1 | 2*t* | Vulnerable exchange rate into the vulnerable subpopualtion |
| *v*2 | 3*t* | Vulnerable exchange rate out of the vulnerable subpopulation |
| *Sr* | 0.9 | Survival following catch and release |
| *vr* | 0.2 | Vulnerable exchange rate out of the refractory subpopulation |
| *pv* | 0.5 | Proportion of fish leaving the refractory state that become vulnerable to the fishery |
| *C*0 | 0.5 | Base catch rate below which recreational anglers derive no satisfaction |
|  | 0.5,1,1.5 | Power parameter defining increase in satisfaction with catch rate |
| *C*50 | 2.0 | Catch rate attracting half of total available effort |
| *C* | 0.5 | Proportional to the rate at which effort increases with catch rate |
| *Emax* | 10 | Maximum effort on any given day |
| *Ot* | {0,1} | Opening switch across days of the year |
|  | |  |
| Derived states | |  |
| *t* | 1/T | Daily time step |
|  | |  |
| State variables | |  |
| *Vt* |  | Abundance of fish vulnerable to the recreational fishery |
| *It* |  | Abundance of fish invulnerable to the fishery |
| *Rt* |  | Abundance of fish recovering from catch-and-release |
| *E*t |  | Daily fishing effort (angler-days) |
| *Ct* |  | Total daily catch in the recreational fishery |

Table 3: Response metrics for schedules 1 (all open) and 3 (open 1 day per week) assuming populations with and without vulnerable exchange.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | All fish vulnerable to fishery | | Vulnerable exchange | |
|  | All open | Open 1 day/week | All open | Open 1 day/week |
| Total catch | 4,431 | 3,583 | 1,202 | 998 |
| Total effort | 1,402 | 498 | 807 | 386 |
| Mean CPUE | 1.9 | 7.0 | 1.3 | 2.4 |
| Value | 21,716 | 28,612 | 2,718 | 3,640 |

1-*pv*

*pv*

*pr*

1-e-*qEt*

Stock available to anglers

*V*

Stock not available to anglers

*I*

*v*1

*v*2

*Sr*

Refractory fish

*R*

Catch

1-*Sr*

Figure 1: Schematic representation of the recreational fishery with three states: vulnerable to fishing (*V*), invulnerable to fishing (*I*) and refractory (*R*). Exchange rates between vulnerable and invulnerable states are represented by *v*1 and *v*2. Catch on day *t* is proportional to effort on that day. All captured fish are released into the refractory state, from which they may die due to release mortality (1-*Sr*) or survive and leave that state at a rate of pr. Fish leaving the refractory state may return to the vulnerable state at a rate of *pv* or the invulnerable pool at a rate of 1-*pv*.



Figure 2: Satisfaction per angler-day (value) as a function of catch-per-unit effort. The value of *C*0 determines the catch rate at which satisfaction is zero;  determines the degree of non-linearity of value with catch rate (Adapted from Cox et al. 2003).



Figure 3: Barplots showing differences in key recreational fishery metrics (mean total annual catch, total annual effort, catch-per-unit effort, and value of the fishery) associated with different opening scenarios. Opening schedules associated with each scenario number are described in the legend.



Figure 4: Within-season dynamics of two fishery management tactics: catch-and-release with the fishery open year-round (left panels); and catch-and-release only open one day per week (right panels). Panels show patterns of vulnerable, invulnerable and refractory abundance (top panels); effort and catch-per-unit effort (CPUE; middle panels); and satisfaction (bottom panels) over time.



Figure 5: Elasticity of fishing value to changes in the key model parameters. Elasticity was calculated as the proportional change in value resulting from a 10% increase or decrease in the parameter value from the base rate (Table 2). The exception was ** (the exponent of the satisfaction function), which was varied as a +/- 10% deviation from 1.0, allowing the function to be exponential or saturating. Up-arrows represent value elasticity following parameter increases; down-arrows represent value elasticity following parameter decreases.



Figure 6: Total annual value derived from a catch-and-release fishery open every day (grey line) or open 1 day per week (black line) across a range of maximum daily effort from 1 to 100 angler-days per hectare.



Figure X: Barplot showing the total annual fishery value associated with different opening scenarios. Opening schedules associated with each scenario number are described in the legend.